

Canadian Translation of Fisheries and Aquatic Sciences

No. 5243

Recipient study in Nordbotn, Kvaloya, 1983-84;
Hydrography and bottom fauna

E. Oug and B. Holte

Original title: Resipientundersokelse i Nordobtn, Kavaloya 1983-84.
Hydrografi og bunnfauna

In: Tromura, 48: 1-41, 1985

Original language: Norwegian

Available from:
Canada Institute for Scientific and Technical Information
National Research Council
Ottawa, Ontario, Canada K1A 0S2

1986

39 typescript pages

Secretary
of StateSecrétariat
d'État

MULTILINGUAL SERVICES DIVISION – DIVISION DES SERVICES MULTILINGUES

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LIBRARY IDENTIFICATION – FICHE SIGNALÉTIQUE

Translated from - Traduction de Norwegian	Into - En English
Author - Auteur Eivind OUG and Borge HOLTE	

Title in English or French - Titre anglais ou français

Recipient study in Nordbotn, Kvaloya, 1983-84;
Hydrography and bottom fauna

Title in foreign language (Transliterate foreign characters)
Titre en langue étrangère (Transcrire en caractères romains)

Resipientundersokelse i Nordbotn, Kvaloya 1983-84.
Hydrografi og bunnfauna.

Reference in foreign language (Name of book or publication) in full, transliterate foreign characters.
Référence en langue étrangère (Nom du livre ou publication), au complet, transcrire en caractères romains.

Tromura, ~~Naturvitenskap~~ No. 48

Reference in English or French - Référence en anglais ou français

Publisher - Éditeur Tromso University,	DATE OF PUBLICATION DATE DE PUBLICATION			Page Numbers in original Numéros des pages dans l'original 1 - 41
Place of Publication Lieu de publication Tromso, Norway	Year Année 1985	Volume	Issue No. Numéro 48	Number of typed pages Nombre de pages dactylographiées 39 +
	ISSN 0332-6195			

Requesting Department
Ministère-Client DFO

Translation Bureau No.
Notre dossier n° 2537225

Branch or Division
Direction ou Division IPB

Translation (Initials)
Traducteur (Initiales) LT

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Client's No.—N° du client	Department — Ministère DFO	Division/Branch — Division/Direction IPB	City — Ville
Bureau No.—N° du bureau 2537225	Language — Langue Norwegian	Translator (Initials) — Traducteur (Initiales) LT	

Eivind Oug and Borge Holte

RECIPIENT STUDY IN NORDBOTN, KVALOYA 1983 — 84;
HYDROGRAPHY AND BOTTOM FAUNA

TROMURA

Tromso Museum Report Series

Tromura, Nat. Sciences No. 48

Tromso University, Institute of Museum Work

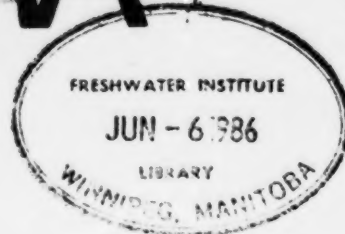
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ISSN 0332-6195

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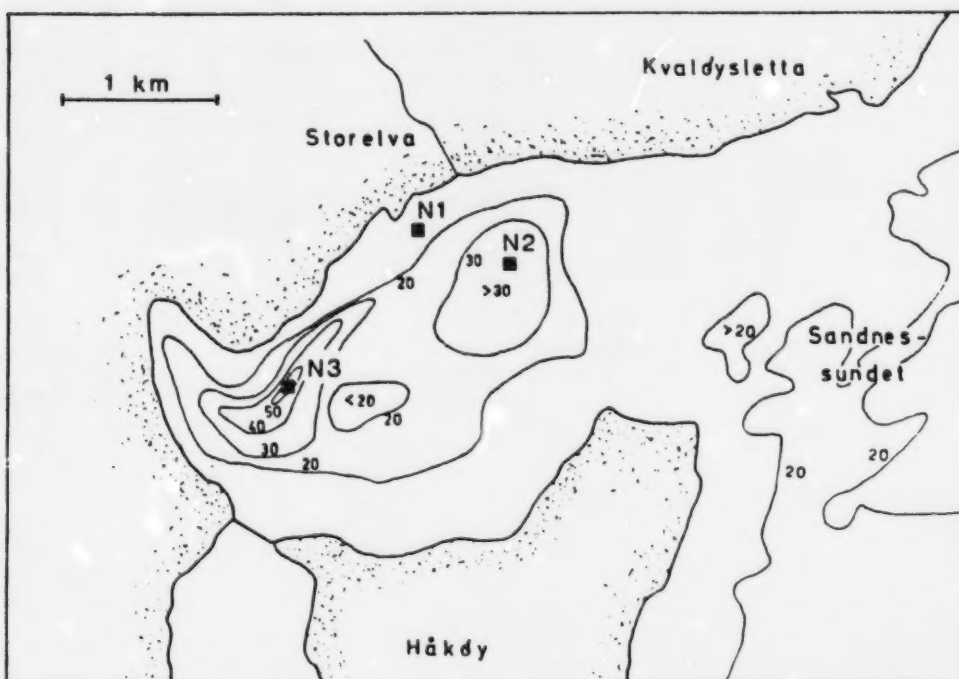
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Resipientundersøkelse i Nordbotn, Kvaløya 1983-84 Hydrografi og bunnfauna.

AV

EIVIND OUG OG BØRGE HOLTE



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PREFACE

The present report is closely linked to the pollution study titled "Base Study of Tromso Sound and Nordbotn 1983" ("Basisundersokelse av Tromsosund og Nordbotn 1983"), prepared by Tromso University and NIVA (Norwegian Water Research Institute) for the Norwegian Pollution Inspection and the municipality of Tromso. The Base Study investigates the effect of the existing discharges on the natural environment and describes the state of the study area. Pollution load is small in Nordbotn, but the area is of current interest as a recipient in connection with future development. Therefore, the University initiated hydrographic measurements in Nordbotn to map the water movements and to describe the oxygen conditions. These studies, together with bottom samples from the Base Study (here added to some further samples), constitute a basis for an evaluation of Nordbotn as a recipient.

The hydrographic samples were collected by F/F Johan Ruud, a vessel owned by the University. Instrument chief Frits Pettersen and administrative secretary Ulf Normann were responsible for the sampling.

The bottom samples were collected by F/F Ottar and processed by Borge Holte. The ^{ie}numeral material was analyzed by means of the University's NORD-500 computer with a software package for marine community analyses, prepared by Ulf Normann.

The report was mainly prepared by Eivind Oug. He also took the initiative for collecting the hydrographic samples and is technically responsible for evaluations and conclusions.

Tromso, November 1985

Eivind Oug

Borge Holte

SUMMARY

Nordbotn, which is situated at Tromsø between Haakoya and Kvaløysletta, is a minor fjord area with a 55-m deep basin and a threshold at 17 m. The present pollution-causing discharges are small, but the area may receive sewage in connection with future development. The aim of the present study was to evaluate Nordbotn for use as a recipient for municipal waste water.

The study comprised hydrography (temperature, salt content, oxygen) and bottom fauna. Hydrographic measurements were carried out at a station (55 m) approximately once a month in the period April 1983 - December 1984. The bottom fauna was sampled with a bottom sampler at three stations (10 m, 35 m, and 55 m) in March 1983.

Temperature varied in the surficial layer between 0.4°C (February) and 11.8°C (July), while salt content ranged from 29.1 ‰ (July) to 33.4 ‰ (April). During the winter months (October - April), the water masses were homogeneous from the surface to the bottom. In the summer months, density declined in the surficial layers, and the thermocline lay at a depth of 20 - 25 m. Below the thermocline, the temperature rose gradually to a maximum in September/October (5 - 6 °C) at the same time as the salt content gradually declined.

The hydrographic measurements showed that in the winter months, the water masses were mixed by free circulation all the way to the bottom. In the summer (May - October), the deep layer below the thermocline was stagnant. No influx of new deep water was registered in the stagnant period. The oxygen content declined slowly to drop to values below 4 mL/L (40 m) in the fall.

All bottom fauna stations had fresh fine-grained sediment, while the deep stations had relatively high organic contents (3 - 5 % organic carbon). A local putrefactive environment was found in shallow water, with H_2S in the bottom sediment.

All stations had bottom fauna communities rich in species (40 - 60 species), dominated by many-bristled worms. The shallow station had an uncommonly high number of individuals (5 200 ind. per 0.4 m^2). Diversity measures (H' , J , rarefaction) and log normal distribution of the numbers of individuals in the species indicated some environmental disturbances in the communities, especially at the deepest station (55 m). This was probably a consequence of the oxygen conditions that prevailed during the stagnant period.

A calculation of decomposition capacity of organic materials in Nordbotn was carried out on the basis of water volumes and oxygen quantities at several depths. The calculations indicate that on the whole, the capacity is high in the entire area but that local oxygen failure may occur even by moderate load (1 000 - 2 000 p.e.). Areas in eastern Nordbotn and the deepest parts are especially vulnerable.

Both hydrographic studies and bottom fauna samples showed that Nordbotn is a vulnerable area. It is concluded that sewage discharges to Nordbotn are not advisable.

Introduction

This report describes the hydrographic conditions and the bottom fauna in Nordbotn with a view to evaluating the area for use as a recipient for municipal wastewater.

Nordbotn is situated between Haakoya and Kvaløysletta in the vicinity of the town of Tromsø (Fig. 1). It is a partially closed part of the fjord, with an opening in the east towards Sandnes Sound. In the south, there is a small and shallow sound leading to Sorbotn south of Haakoya. Between Nordbotn and Sandnes Sound, there ^{is} a threshold ~~at~~ about 17 m. Large parts of the Nordbotn basin have depths of 25 - 35 m, with the greatest depth at about 57 m (Fig. 2).

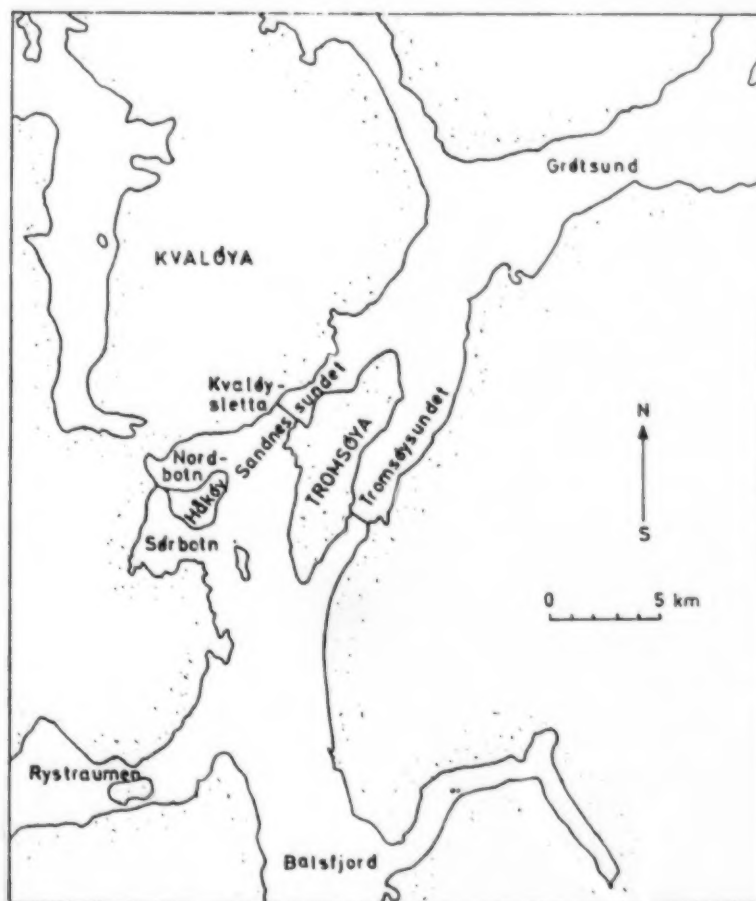


Fig. 1

At present, Nordbotn has a relatively small pollution load from wastewater. Calculated discharges total 600 population equivalents (p.e.) deriving from scattered housing and mechanical industry. However, the Tromsø municipality is planning to locate a major development area at Storelva south of Kvaløysletta (Fig. 2). After the completion of the area, its discharges will correspond to 7 500 p.e. The proposal concerning the control plan (first round of discussions) includes a request for using Nordbotn as a recipient. It is proposed that wastewater be collected for discharge near the mouth of Storelva (Tromsø Municipality 1984).

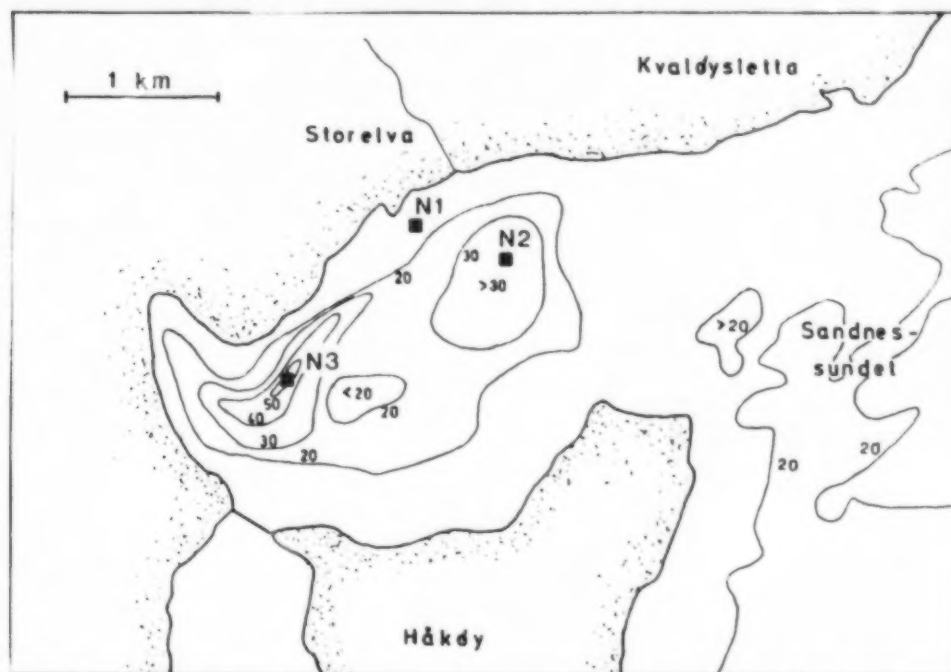


Fig. 2 The Nordbotn basin showing depth isopleths and location of bottom sampling stations (N1 - N3). Hydrographic samples were taken at station N3. Depths are indicated in meters.

In general, threshold fjords are little suited for use as recipients for domestic sewage and wastewater. The water frequently changes poorly, and part of the year the deep water stagnates without a supply of fresh oxygen. There is a risk that sinking waste materials and natural organic material accumulate on the bottom, using up oxygen for decomposition. Local hydrographic conditions and the depth of the threshold are crucial

factors in view of a fjord's water exchange, which again determines the oxygen supply and at the same time the amount of organic material that can be decomposed.

In oxygen-free environments, putrefaction leads to the formation of toxic and ill-smelling gases. The most notable of these is hydrogen sulfide gas (H_2S). The gases may also be released into water masses and come up to the surface periodically. Such putrefactive environments are lifeless, and the gases constitute a threat against life in the surrounding oxygenic environments.

No hydrographic studies have been carried out in Nordbotn earlier, but some information on currents in the surficial layers is found in Naeser et al. (1975). Also, Tromsø Sound and Sandnes Sound are well known due to longterm work concerning both their hydrography and currents; see e.g. Hognestad (1976), Naeser et al. (1975), Bech (1982), Jakola (1982) and Holte (1982). Saalen (1950) studied conditions in fjords in Troms, where several of them had thresholds. He found that there were great variations between the fjords and that in general extensive water exchanges took place every year.

The present study mainly aimed to map the stagnation and exchange of the deep water in Nordbotn. The measurements also constitute the basis for a rough calculation of how big a capacity for decomposition of organic waste the area possesses.

Bottom fauna samples are a measure of the environmental state of Nordbotn at present. Bottom organisms are stationary and therefore have to adapt themselves to the place they live in. Favorable environmental conditions are characterized by species-rich organism communities, with typical patterns of distribution of individuals among the species. If a community is exposed to pollution or other environmental disturbance, many species disappear and the distribution of individuals changes among the species that recover. Analyses of the structure (number of species, distribution of individuals, diversity) of organism communities make it possible to judge the environmental quality of a sampling location.

HYDROGRAPHY

Methodology

The measurements involved temperature, salt content, and oxygen. They were carried out from the University's vessel "F/F Johan Ruud" with a Neil Brown Instruments Mark III CTD probe permanently installed onboard. Values were recorded at each five meters throughout the water columns. The measuring location is shown in Fig. 2.

The measuring was began in April 1983, to continue to December 1984 (Table 1). The measuring work was fitted in between other activities of the expedition, which resulted in different intervals between each series of measurements.

The oxygen detector of the CTD probe was somewhat unstable, which resulted in some measurement series with too low or too high values. In fall 1984, the oxygen values were checked against oxygen samples titrated in accordance with Winkler's method.

The results for temperature and salt content are presented in the form of isopleth diagrams. The curves were drawn up by interpolation between the measuring points. The CTD probe also calculates values for density based on temperature and salt content measurements.

Table 1 : Data concerning hydrographic measurements :

1983 :	7.4	16.6	3.7	29.7	12.9	28.11	12.12		
1984 :	9.1	3.2	11.4	20.5	8.6	14.9	19.10	6.11	10.12

Results

Complete measuring results are given in Table 3, Appendix.

Temperature

Temperature changes were similar in the two study years (Fig. 3). In the six winter months, the temperature was low and even in the entire water column and rose gradually from mid-winter til April.

The summer-related warming of water started in the surficial layers in mid-May and resulted in obvious temperature gradients down to a depth of about 20 m. Under the thermocline, the temperature rose gradually to maximum values in September. Due to cooling in the fall, the temperature gradients collapsed in September/October, after which the temperature kept dropping in the entire column until mid-winter. Due to the long intervals without measurements in fall 1983 and summer 1984, the descriptions for these periods are less accurate than the rest. Most probably, the temperature drop in fall 1983 was time-wise more concentrated (especially in the deep layer) than indicated by the interpolated curves, and similarly the surface temperature in summer 1984 must have been higher than indicated.

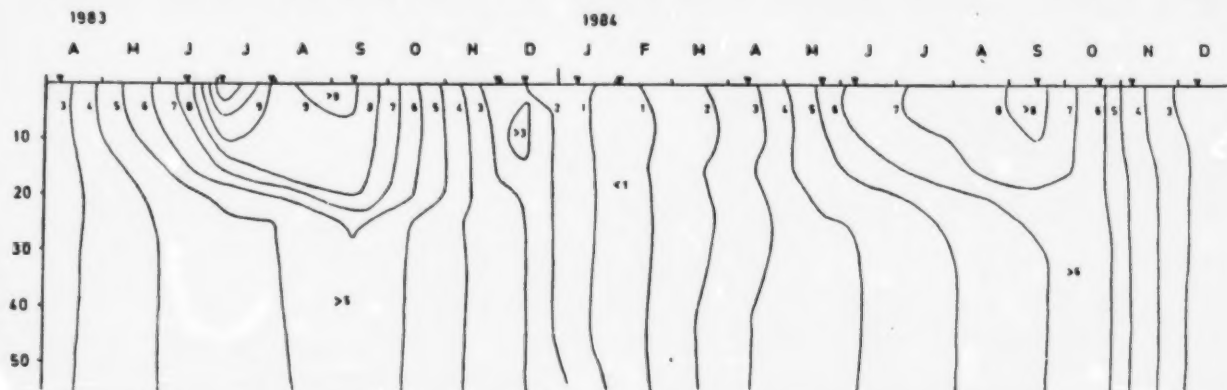


Fig. 3 Temperature variations ($^{\circ}\text{C}$) in the study period. Triangles mark measuring times.

Salt content

The salt content was relatively even in the whole water column in the 6 winter months until May both in 1983 and 1984 (Fig. 4). The summers were characterized by reduced salt content in the upper layers of water, while changes were small in the deep layers where the salt content declined evenly and gradually later in the fall. In 1983, this development continued until December, while at the end of 1984, a slight rise was registered in the salt content from the end of October.

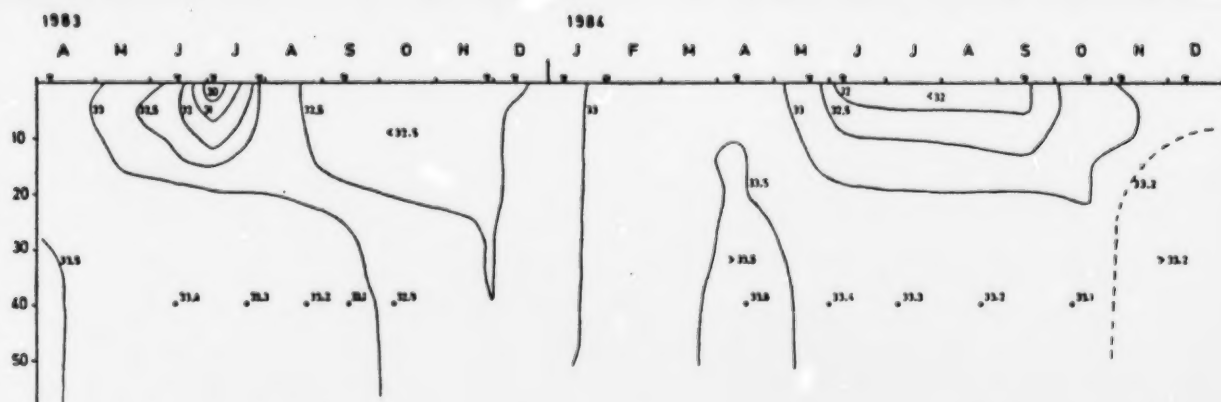


Fig. 4 Salt content variations (o/oo salt) in the study period. Decimal values are given for 40 m. Triangles mark measuring times.

Density

Density calculations show that the water masses were homogeneous from October to April in both years (Fig. 5 : Profiles for December, January and February, which are vertical, are not included). Therefore, the water circulation must be free in the winter all the way to the bottom. Measurements carried out in the summer months showed clearly layered water masses with reduced density above the threshold depth. In 1983, there was a sharp distinction between the water layers, indicated by breaks in the profiles just below the threshold depth, while there was a more even transition between the deep layer and the water masses above it in 1984. Density was homogeneous in the deep layer in the summer months as well but declined gradually from a maximum in April to a minimum before vertical movement in the fall.

In this period, no replacement of the deeper water took place (it can not be displaced by lighter water), but the density decline that was attributed to an even loss of salt and slow heating, indicates that internal mixing processes took place in the deep layer.

Oxygen content

Oxygen in water masses is used up by the respiration and bacterial decomposition of organic material. Renewal of oxygen takes place only in the upper layers, where it enters either directly from the air or by means of photosynthesis of plants (algae). In a thoroughly mixed water mass, oxygen content is normally high and even in the entire water column (in excess of 7 mL oxygen per 1 L of water). On the other

hand, in a stagnant deep layer, where renewal can not take place, oxygen is gradually consumed.

The measurements indicated that the oxygen content of the water masses was varying but quite evenly distributed in the 6 winter months (Fig. 6). The values were especially high in April, most probably due to the blooming of the plant plankton. In the summer half-year, oxygen content decreased gradually in the deep layer. In depths greater than 40 m, more than half of the oxygen was consumed, and it dropped to values below 4 mL/L in the fall.

The Winkler analyses in October 1984 gave results highly conforming with the simultaneous CTD measurements (Table 2). The measurement series of November and December did not correspond as highly, but the deviations were not big enough to suggest that the CTD probe would not give quite correct measurements.

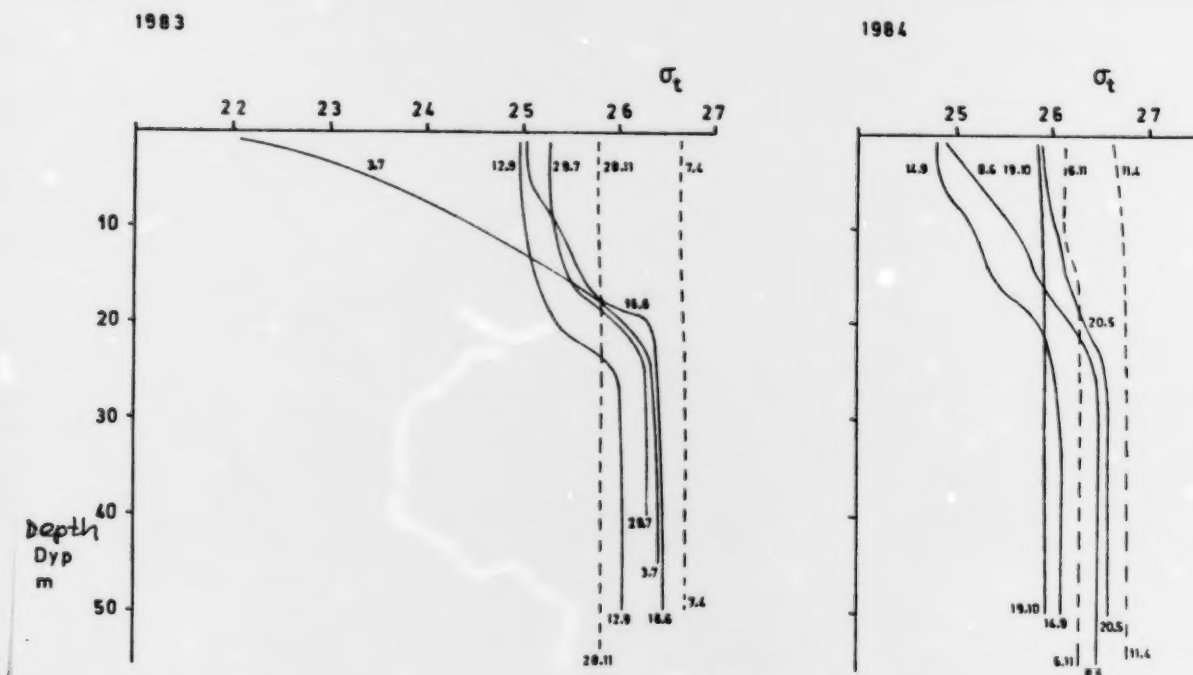


Fig. 5 Calculated density profiles (σ_t) in 1983 and 1984. The dashed lines show measurements in the winter half-year.

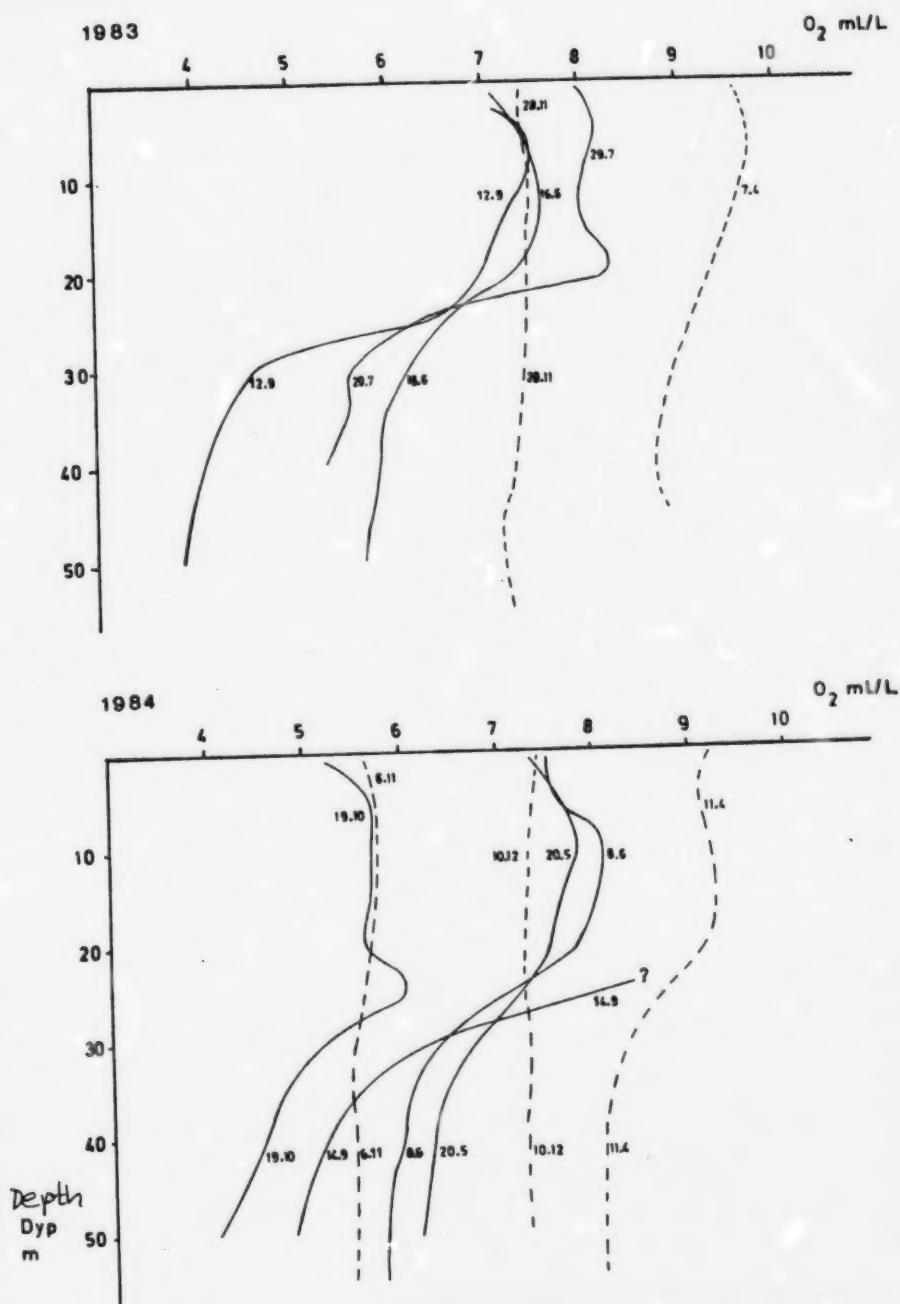


Fig. 6 Dissolved oxygen in water masses in 1983 and 1984. Dashed lines show measurements in the winter half-year.

Table 2 Oxygen measurements by the CTD probe, compared with Winkler-titrated water samples (mL oxygen/L).

Depth Dyp, m	19.10.84		6.11.84		10.12.84	
	CTD	W	CTD	W	CTD	W
0	5.26	5.68	5.66	-	7.43	-
10	5.68	5.64	5.75	-	7.31	-
20	5.61	5.61	5.68	-	7.25	-
30	5.20	5.63	5.49	-	7.30	-
40	4.56	4.41	5.50	6.05	7.24	6.51
50	4.05	3.93	5.47	6.22	7.26	6.50

In September 1984, very high oxygen values were registered in the 0 - 20 m layer. This was assumed to result from a functional error in the instrument. The measurements are not included in Fig. 6.

Summary

The hydrographic conditions in Nordbotn are normal for a threshold fjord. In the six summer months, the water masses are layered, with light surficial layers which literally float on the heavier and more homogeneous deeper water. The surficial layers can easily pass over the threshold, and their temperature and salt content vary in the same manner as those of the surrounding fjord system. In the deep layer, changes are even and slow, the temperature rises and the oxygen content declines. These changes are typical of a stagnant deep water with no replacement of the water masses. In Nordbotn, this situation seems to go on for about half a year, but there annual variations as to the true length of the period.

The water masses are homogeneous in the winter months, with very small differences in all measuring parameters from surface to bottom. This shows that the mixing is thorough and that the vertical motion reaches all the way to the bottom. The present study can not, however, establish to what extent this motion results in a replacement of water masses in Nordbotn. In principle, the same water masses may stay and circulate in the area. On the basis of trials with models

of surface currents, Naeser et al. (1975) described Nordbotn as an area with poor water replacement. However, the increase of the salt content in the winter shows that new water enters from the outside. In the 1983-84 winter, this was noticeable only after the new year, while the year before it started already in November.

Deep water in threshold fjords can be replaced also in stagnation periods, if water masses with high density rise to the threshold level and enter the fjord. If the water entering the fjord is the heaviest, it displaces the existing deep water. Saelen (1950) shows that both vertical motion and influxes are important for renewal of deep water in North Norwegian fjords and that local variations may be great. In Balsfjorden, vertical motion normally reaches the bottom in the winter, and in the spring and early summer there is a significant influx of deep water, indicated by increase in salt content and temperature (Saelen 1950, Eilertsen et al. 1981). No influxes of deep water are registered in Nordbotn in the summer half-year, when the water masses are layered. In the winter, new water seems to mix with the existing water by means of vertical motion.

BOTTOM FAUNA

Methods

Field methods and laboratory work

Samples of the bottom fauna were collected with a 0.1 m^2 van Veen bottom sampler at three stations in different depths (10m, 35m, 55m)(Fig. 2). The samples were immediately sifted with 5 mm and 1 mm sifters, and the resulting material was preserved. The species of all animals were identified, and the number of individuals of each species determined.

The samples were collected on March 23 1983. Four parallel samples were taken at all stations. Three of the parallel samples were processed in the "Basic study", where the Nordbotn stations were discussed together with the Tromsø-sund stations (Oug et al. 1985).

A description of the bottom sediments was prepared at each station as well.

Data processing

The numerical material constituted the basis for the description of the fauna composition and species diversity at each station. For the analyses, the four sets of parallel samples were combined, to make them represent a larger bottom area.

Species diversity was measured by using indexes and curves for diversity. High diversity means that a community consists of many species without special dominant species such as are usually found in unaffected soft-bottom areas with stable environmental conditions. The diversity declines under less favorable conditions where fewer species can survive. Diversity measures can therefore be considered to be indicators of how "normal" a community is and whether it is exposed to any environmental stress. Two indexes are used, H' (Shannon-Wiener index) and J (uniformity). H' refers to both number of species and distribution of individuals among the species sampled, while J is a measure of how uniformly individuals are distributed over the species. The diversity curves are produced after a method by Hurlbert (1971). It shows

the number of species as a function of the number of individuals. Number of species per 100 individuals is also calculated from the curves in the form of an index (S100). The diversity curves are explained in greater detail in Appendix 1, which also contains the formulas used.

Distribution of individuals over species is also obtained by means of log normal distribution. The species are grouped in accordance with the number of individuals by the following system (ind. per species) : 1, 2-3, 4-7, 8-15, 16-31, etc. (with doubled quantity for each class). Experience has shown that the resulting curve will, for an unaffected bottom fauna community, correspond to a discontinuous normal distribution (see Fig. 8). When pollution is moderate, the curve becomes smooth and extends towards the higher classes or develops extra peaks. When pollution is strong, the plotting results in several peaks without any obvious pattern (Gray & Pearson 1982). Appendix 1 contains a more detailed description of the method.

Results

Bottom sediments

All stations had fresh fine-grained sediment (Table 3). However, the deep basin also showed high organic content values. The values were similar to those in the deep areas of Tromsø Sound (Oug et al. 1985).

Table 3 Visual observations of bottom sediments at sampling stations in Nordbotn (N1 - N3) and organic carbon content (% C) of bottom sediments. The % C values were measured by NIVA and taken from the "Basic Study" (Oug et al. 1985).

Station	Depth; m	Sediment	% org. C
N1	10	Grey fine mud, some coke pieces	1.79
N2	35	Dark grey, fine mud	4.33
N3	55	Dark grey, fine mud	3.66

A local putrefactive environment was found in a somewhat shallower place close to station N1. The bottom sediment was black and smelled of hydrogen sulphide. Most probably this putrefactive environment had been formed in the

same manner as it is known to have formed in other places in the Tromso area (Oug et al. 1985). The samples contained abundant Desmarestia aculeata and decomposing plant remains. D. aculeata lies on the bottom like a carpet and acts as a trap for other organic material that will stick to it and decompose. However, this observation shows that local accumulation of organic material takes place in Nordbotn. There is reason to believe that the situation will become worse, if the influx of material increases.

Fauna

Table 4, Appendix, contains the results for all samples. The table shows the number of individuals (per 0.4 m²) for the most important species at the three stations. Bristle worms were the dominant group of animals at all stations, with regard to both number of species and number of individuals. There was an obvious difference in the composition of fauna between stations N1 and N3, as they had no dominant species in common. All stations had normal numbers of species, while station N1 had an exceptionally high number of individuals.

Several of the dominant species at Station N1 were common soft-bottom forms occurring throughout the Tromso area. Besides, the bristle worms Chaetozone setosa, Heteromastus filiformis, Scoloplos armiger, and species of the family Polydora were frequently numerous in bottom sediments with a high organic content, and they are tolerant of organic pollution. On the whole, the fauna of this station was similar to that of other shallow stations in the Tromso area (Oug et al. 1985).

At the deep stations, the composition of the fauna differed from that in the deep areas of Tromso Sound. The "Basic study" (Oug et al. 1985) shows this clearly. However, station N3 showed several similarities with the fauna in the deep basin at Svartnes, Balsfjorden (190 m), where particularly Myriochele oculata is a common species (Oug, unpubl.). The large occurrence of Macoma calcarea is noteworthy. This is usually a shallow-water species, but it seems to prefer black soft sediments. The species may favor the organic content of the sediment in the deep basin.

Table 4 Dominant species and related numbers of individuals at stations N1 - N3 in Nordbotn. The area studied was 0.4 m² per station.
 MB = many-bristled worms K = crustaceans B = ribbon worms
 M = bivalves

Station		N1	N2	N3
Polydora socialis	MB	1113	-	-
Polydora quadrilobata	MB	333	1	-
Protomedea fasciata	K	321	1	-
Spio filicornis	MB	121	1	-
Corophium crassicornis	K	82	-	-
Capitella capitata	MB	109	9	-
Anaitides maculata	MB	38	2	-
Harmothoe imbricata	MB	36	4	3
Chaetozone setosa	MB	479	39	3
Heteromastus filiformis	MB	1823	34	2
Scoloplos armiger	MB	220	23	29
Pholoe sp.	MB	175	3	23
Nemertini ind.	B	161	37	36
Paradoneis lyra	MB	73	2	57
Sabellides borealis	MB	1	112	32
Cossura longocirrata	MB	-	42	8
Euchone papillosa	MB	-	34	17
Pectinaria koreni	MB	1	23	11
Macoma calcarea	M	13	61	229
Owenia fusiformis	MB	11	10	953
Myriochele oculata	MB	-	1	727
Nuculana pernula	M	-	9	26

Species diversity and log normal distribution

Fig. 7 shows diversity curves drawn up according to Hurlbert's method. The higher the curves lie in the diagram, the higher the diversity is. For comparison, stations from nearby areas and South Norwegian fjords are included. S2A (Sorfjorden) represents an obviously polluted site, while H20 (Singlefjorden) is from an unaffected area.

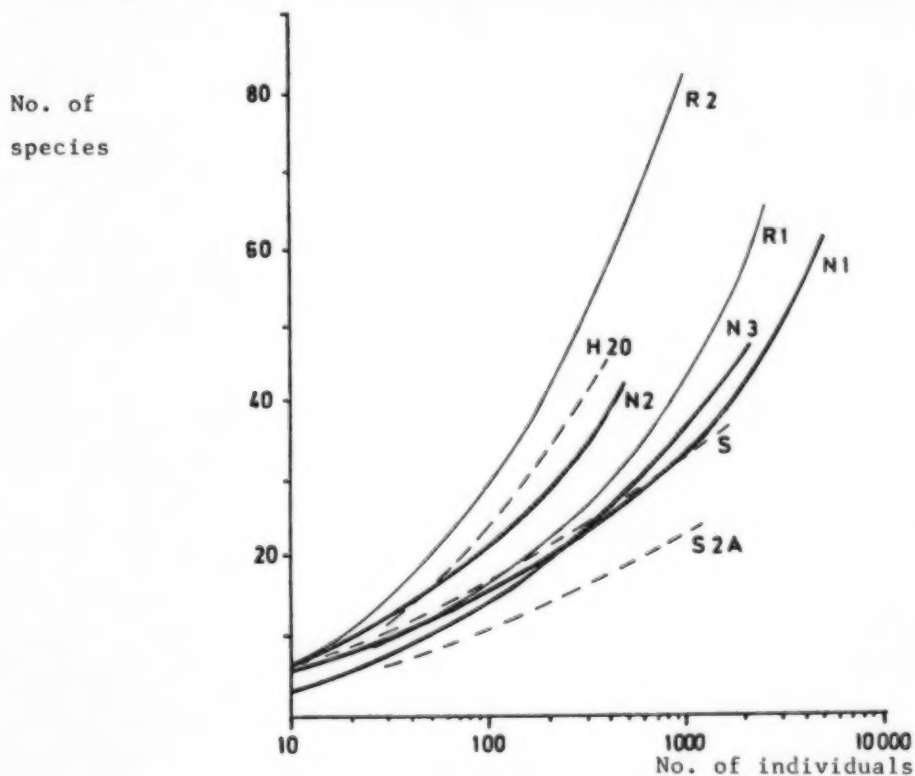


Fig. 7 Diversity curves after Hurlbert's method for stations in Nordbotn and selected reference stations.

Locations :

R1 : Kvaloya, N of Sandnes Sound bridge (depth 7 m).

R2 : N of Tromsoya (depth 40 m).

S : Svartnes in Balsfjord (190 m).

S2A : Sorfjorden in Hardanger.

H20 : Singlefjorden in Ostfold.

R1 and R2 are stations from the "Basic study" (Oug et al. 1985) (with four parallel samples here). S2A and H20 are taken from Rygg (1984).

Station N2 had a fairly normal diversity, but the values were clearly lower than those for corresponding depths N of Tromsøya (R2) and lower than those for Singlefjorden. Both N1 and N3 had reduced diversities, falling between unaffected and polluted positions. N1 may have been affected by the putrefactive environment nearby, but in general, shallow-water positions in the Tromsø area seem to be unstable and exposed to disturbances that may result in reduced diversity (Oug et al. 1985). N3 is comparable with the deep basin in Balsfjorden (S). The fauna of threshold fjords is most probably exposed to a given environmental stress because of the periodically stagnant water masses.

Table 5 shows the diversity index values. Normally, H' obtains values >3.0 for stable communities and values <1.0 for clearly affected communities. J shows values between 0 and 1, and a low value indicates quite unbalanced individual distribution between species. Station N3 obtained the lowest values. Also diversity indexes indicate that there are some disturbances at N1 and N3.

Table 5 Total number of species, total number of individuals, and values for diversity indexes at bottom fauna stations in Nordbotn.

Formulas for the indexes are given in Appendix 1.

Station	N1	N2	N3
Total of species	61	42	47
Total of individ.	5248	496	2282
H'	3.15	3.93	2.54
J	0.53	0.72	0.45
S_{100}	15.2	21.4	13.8

Fig. 8 shows the logarithmic normal curves. All stations in Nordbotn had curves deviating from the normal distribution form, although there were no indications of severe environmental disturbances. Obvious similarity was found between the curves for N1 and R1 and for N3 and S (Svartnes).

However, N3 differs from S in that it has peaks at higher classes (towards right on the curve), which is a common expression of organic enrichment in the sediment. Stations N2 and N3 also showed deviation in relation to the evenly deep station R2 N of Tromsøya. The latter is assumed to be unaffected by organic pollution and has a curve showing relatively high conformity with the ideal form.

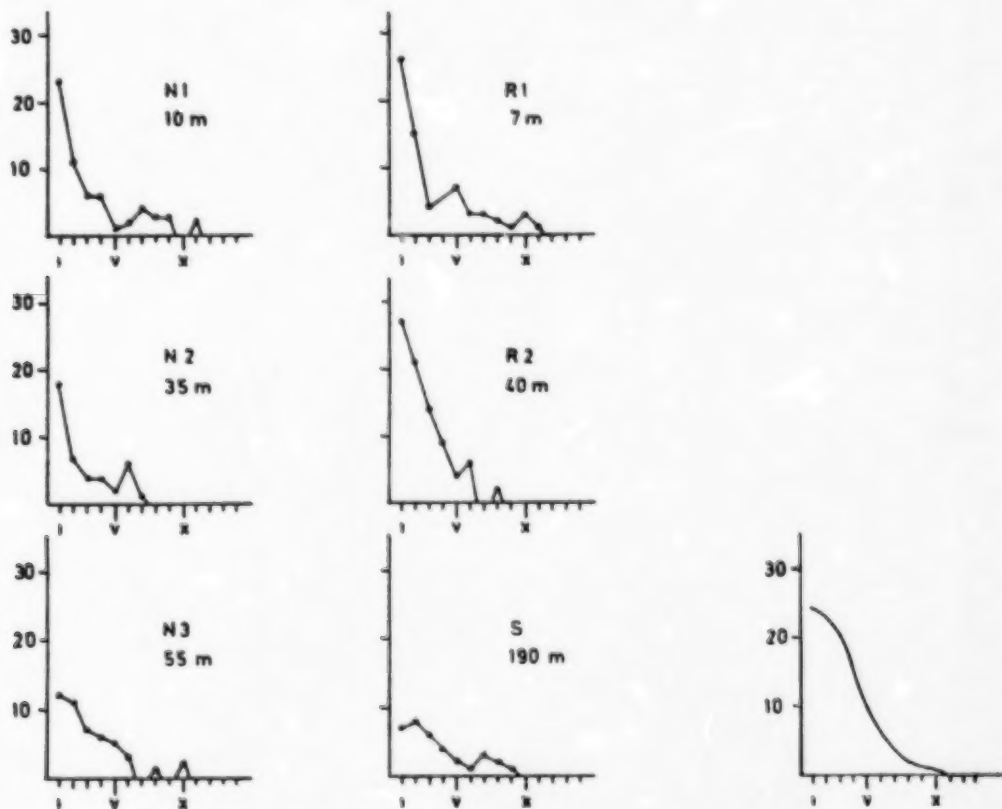


Fig. 8 Log normal plot representing numbers of individuals for species at stations in Nordbotn and selected reference stations (see Fig. 7 for locations). Classes based on numbers of individuals are placed along the X-axis (I = 1 ind., II = 2-3 ind., III = 4-7 ind., etc.), while the Y-axis indicates number of species in each class. At the lower right, an "ideal curve" for an unaffected community.

Summary

The bottom-living animal community in the deep area of Nordbotn is characterized by a certain degree of organic pollution. The deepest station (N3) had reduced diversity, and both N3 and N2 had logarithmic normal curves indicating environmental stress. This is probably related to oxygen conditions, which can, already at present, be critical for many bottom-living animals. Oxygen values are normally lower at the bottom than in the water masses above it because of oxygen consumption in the sediments. However, the conditions at the bottom can be described to be reasonably good, not least because the sediments were fresh and free of odor. On the other hand, the bottom fauna samples confirm that the environment of the deep basin is vulnerable and that it can easily develop a pollution overload when the influx of organic material increases.

The shallow-water station (N1) seems to be exposed to environmental disturbances as well. This is, however, a common situation in the shallow areas of the Tromsø region, and it can be attributed to currents, back eddies, etc. near land (Oug et al. 1985). In some places the conditions allow the formation of local putrefactive environments. The conditions prevailing at N1 are most probably influenced by the adjacent putrefactive environment, which is possibly indicated by the rich occurrences of the bristle worm Heteromastus filiformis, frequently found in places with organic enrichment.

DECOMPOSITION CAPACITY IN NORDBOTN

During its stagnant period, the deep water layer traps materials sinking through the water masses. Most probably much of the organic material brought from land, both naturally and by drainage of effluents ends up in the deep layer, because water transport in the surficial layers is too weak to bring it over the threshold. Plankton algae, which die after blooming, sink to the deep layer as well.

Under the present circumstances, oxygen consumption in the deep layer is moderate. It is probable that most of the consumption can be attributed to the respiration of living organisms and the bacterial decomposition of natural material (plant remains from land, dead plankton, etc.). The existing discharges of effluents are less significant. It can be assumed that the oxygen consumption stays the same from year to year. However, new and bigger

discharges of effluents will increase the quantities of organic material, which will increase the oxygen consumption. In the deep area this may lead to exhaustion of all oxygen. Even a reasonable increase in the oxygen consumption is unsafe, since a risk of significant damage to the environment occurs at oxygen contents lower than 2 mL/L.

Table 6 gives the results of a calculation concerning the quantities of effluents which, introduced to the deep layer, would lead to critical conditions at the end of the stagnant period. The table shows how much organic waste can be decomposed, for each 5-m depth interval, by consumption of all remaining oxygen or by consumption down to a residual content of 2 mL/L. The quantities are converted to person equivalents for the whole stagnant period, which is set at 180 days. A separate calculation was made for the deep area outside Storelva (Fig. 2). Appendix 2 gives the units and the conversion constants.

Table 6 Calculated decomposition capacity of organic material in Nordbotn in person equivalents (p.e.) by consumption of all oxygen and down to residual level 2 mL/L.

A. The whole deep basin.

B. Area deeper than 30 m outside Storelva.

	Deep area m	Volume m ³	Full consumption p.e.	Residual 2 mL/L p.e.
A.	< 20	74 700 000		
	20 - 25	9 600 450	6 755	4 764
	25 - 30	5 783 910	3 170	1 970
	30 - 35	3 117 960	1 431	785
	35 - 40	1 379 900	603	316
	40 - 45	473 920	196	98
	45 - 50	190 530	77	38
	50 - 55	55 170	22	10
	> 55	12 500	5	2
	Sum	95 314 340	12 259	7 983
B.	> 30	1 618 540	743	407

The calculations indicate that on the whole, there is enough oxygen in the water masses of the deep layer to break down larger quantities of sewage. The capacity is significant in the first two depth intervals, mainly because these consist of large volumes of water. In reality, much of the waste sinks to the bottom for decomposition, with the result that oxygen consumption becomes significantly greater in the bottom than in the water masses above it. Much of it also accumulates at the discharge sites. Therefore, it can be assumed that the exposed bottom areas become oxygen-free in stagnant periods in spite of an abundant supply of oxygen in water masses elsewhere.

The deepest areas of Nordbotn are particularly vulnerable. Water volumes are small (and the bottom area is large compared to the water volume), while simultaneously the distance to more highly oxygenic water is long. The calculated low decomposition capacities mainly result from the small water volumes, but they illustrate clearly how little more is needed to produce an oxygen failure.

The area outside Storelva (Fig. 2) will be severely exposed, when discharges are made in the eastern part of Nordbotn. It has been calculated that decomposition capacity in depths greater than 30 m is around 100 p.e., which corresponds to about 10 % of the planned effluent discharges from the Storelva area. It must be assumed that in this area as well, a relatively small pollution load will cause oxygen failure on the bottom.

DISCUSSION

Both hydrographic studies and bottom fauna samples have shown that Nordbotn is a vulnerable area. In the deep basin, water replacement is too weak to ensure a stable oxygen supply through the year. Even under today's conditions, respiration and decomposition processes consume an essential part of the oxygen in the deep layer during the stagnant period. Bottom samples indicated that the sediments receive a fair amount of organic material. Animal communities exhibited obvious signs of environmental disturbances. Such conditions are common in threshold fjords. Similar observations were made by Wikander (1983) in Presteidfjorden, Nordland, where natural sedimentation also results in a high organic content in the sediment and affects the animal communities.

Further discharges of sewage to Nordbotn will lead to increased oxygen consumption and create a risk of oxygen failure. Even though the decomposition capacity is generally good in the area, local problems can be expected both in shallow water and deep areas. It has been found out that particle material is deposited in depressions and back eddies, where strongly putrefactive environments may form even if there is oxygen in the water masses around. The deepest parts of the deep area and areas close to a discharge place are especially exposed. The size of the areas involved depends, however, on a number of conditions and is difficult to calculate. The most critical factors are how the pollution components are spread with the surface currents in Nordbotn and how much is held suspended in the water long enough to be transported out over the threshold.

As it is assumed that a third of the sewage discharged sinks to the deep layer, a discharge of 2 000 p.e. at Storelva will overload the whole eastern part of Nordbotn. Even a discharge of 1 200 p.e. would be critical.

Also Naeser et al. (1975) advised against major sewage discharges into Nordbotn, on the basis of experiments with currents. The authors pointed out that there is a risk that solid substances settle on the bottom because of weak water movement in the surficial layers. The current experiments also showed that Nordbotn is exposed to some influx of pollutants from Sandnes Sound. Such an influx is difficult to quantify, but it may contribute to the oxygen consumption that is observable at present. The influx may increase, as the development of the Kvaløysletta site results in increased discharges into Sandnes Sound.

An aspect that was not considered during the calculations is that an entry of nutrient salts (nitrates, phosphates) with waste water may lead to increased plankton growth in Nordbotn. This is a problem in many fjords, where large quantities of dead plankton organisms sink into the deep layer to decompose there, which may increase oxygen consumption in an essential degree.

Thus, it must be concluded that sewage discharges into Nordbotn are not advisable. Today, the area constitutes a recreationally attractive, slightly affected natural environment. That the use of the area will increase when the Storelva site is fully developed, is an argument in favor of preserving the area for the future in a condition as unaffected as possible.

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APPENDIX 1 : Statistical methods

Diversity measures

Diversity is a concept expressing variety of the fauna/flora in a location. Mathematically, diversity is calculated by a relation between number of species and number of individuals in the species. There are several different measures for diversity. Some researchers emphasize species abundance (measure for species abundance), others pay more attention to distribution of individuals over the species (measures for uniformity and dominance). Different measures thus describe different aspects of a community. Diversity measures are "a classic" in pollution studies, because environmental disturbances always affect the composition of communities.

Diversity indexes

The much used Shannon-Wiener index (Shannon & Weaver 1963) is obtained from the following formula :

$$H' = - \sum_{i=1}^s \frac{n_i}{N} \ln \left[\frac{n_i}{N} \right]$$

where n_i = number of individuals of species i , N = total number of individuals, and s = number of species. The index refers to both number of species and quantitative distribution between species, but it seems that it is most sensitive to distribution of individuals.

Uniformity (J) is calculated from H' by assuming that $J = H' / \ln s$ (Pielou 1969). $\ln s$ = maximum value for H' , when all species have the same numbers of individuals (maximum uniformity). Values for J lie between 0 and 1.

Diversity curves

Diversity can be expressed graphically by presenting number of species as a function of number of individuals. Using the total numbers of species and individuals in a sample, calculations can be carried out to find out how many species can be expected to occur in sub-samples with fewer individuals.

Thus, diversity measure becomes independent of sample size and makes it possible to directly compare locations with different densities of individuals. Hurlbert (1971) presented a method for working out such diversity curves based on probability calculation. The following expression is used :

$$E(s) = \sum_{i=1}^s \left[1 - \frac{\binom{N - n_i}{n_d}}{\binom{N}{n_d}} \right]$$

where $E(s)$ = expected number of species in a sub-sample consisting of N_d individuals, and the whole sample consists of N individuals, s species and n_i individuals of each species. The method is described by Rygg (1984) as well.

Log normal distribution

Log normal distribution is a theoretical function with which individual distribution over species in unaffected communities has proven to conform well. Species are grouped, according to numbers of individuals, in classes growing bigger with a given factor. The common method is to draw up the classes so that class I = 1 individual per species, class II = 2 - 3 individuals, class III = 4 - 7 individuals, class IV = 8 - 15 individuals etc, with the class boundaries progressing geometrically with a factor of 2. When the numbers (or percentages) of species are plotted with the classes on a linear scale, a curve is obtained that gives the individual distribution over species in a community. Samples from unaffected communities contain many species with small numbers of individuals, so that the curve begins high up on the Y axis. Some species have moderate numbers of individuals, while only a few species dominate. It has been shown that these curves, plotted for communities from very different ecosystems, evenly slope towards the X axis and conform well to a discontinuous normal distribution (Gray & Pearson 1982). The distribution is called log normal, because the classes are geometric. When pollution is moderate, some species with small numbers of individuals disappear, while some, finding the conditions favorable, increase in numbers. Thus, the curve becomes smoother and extends towards the higher classes or develops extra peaks. When pollution is severe, only a few species survive, but these may be very abundant. Under these conditions, the curve loses every resemblance to normal distribution. Therefore, deviation from the normal distribution

form must be interpreted as an indication of stress, and this method has proven to produce early manifestation of environmental disturbances (see examples in Pearson et al. 1983).

APPENDIX 2 : Decomposition capacity in deep layer

The calculations were carried out for each 5-meter depth interval below a depth of 20 m. Total quantities of available oxygen were calculated from water volumes and oxygen contents at the end of the stagnant period and set up like the measured values from September 1983.

Water volumes were calculated by using the expression for a straight truncated cone :

$$V_i = \frac{h}{3} (A_i + A_{i+1} + \sqrt{A_i A_{i+1}})$$

where h = depth interval (= 5 m) and A (end planes of cone) = areas of upper and lower depth level. The areas, obtained from the depth contour lines in Fig. 2, are given in App. table 1.

Appendix table 1 : Calculated areas (horizontal planes) at different depths in Nordbotn.

Depth, m	Area, m ²
0	5 375 000
20	2 310 000
25	1 555 000
30	800 000
35	462 500
40	125 000
45	67 500
50	15 000
55	7 500

Conversion factor for oxygen content :

$$1 \text{ mL/L} = 1.4 \text{ mg/L} = 1.4 \text{ g/m}^3$$

Conversion to number of person equivalents (p.e.) is based on fixed oxygen consumption per person equivalent/day (=BOF 7) and length of stagnant period (= 180 days).

BOF 7 (decomposition for 7 days) = 75 g O₂
(after Bergheim & Rosseland 1981)

Appendix table 2 shows the number of p.e. by consumption of all oxygen (= oxygen quantity in Sept. 1983) and consumption til a residual content of 2 mL/L (= 2.8 mg/L).

Appendix table 2 : Calculated values for water volumes and oxygen quantities at different depths in Nordbotn. Oxygen quantities are converted to p.e. for the whole stagnant period.

A. The entire deep basin

B. Area deeper than 30 m outside Storelva.

A.	Deep area	Volume	Total consumption			Residual 2 mL O ₂ /L		
	m	m ³	mg/L	kg O ₂	p.e.	mg/L	kg O ₂	p.e.
	< 20	74 700 000						
	20 - 25	9 600 450	9.5	91 204	6755	6.7	64 323	4764
	25 - 30	5 783 910	7.4	42 800	3170	4.6	26 605	1970
	30 - 35	3 117 960	6.2	19 331	1431	3.4	10 601	785
	35 - 40	1 379 900	5.9	8 141	603	3.1	4 277	316
	40 - 45	473 920	5.6	2 653	196	2.8	1 326	98
	45 - 50	190 530	5.5	1 047	77	2.7	514	38
	50 - 55	55 170	5.4	297	22	2.6	143	10
	> 55	12 500	5.4	67	5	2.6	32	2
Σ		95 314 340		165 540	12 259		107 821	7983
B. Outside Storelva								
	> 30	1 618 540	6.2	10 034	743	3.4	5 503	407

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Appendix table 3 : Complete results from hydrographic measurements :
 Temperature ($^{\circ}\text{C}$), salt content (promille),
 density ("Sigma" T) and dissolved oxygen (mL/L).
 The measurements were carried out in the deep area
 of the Nordbotn Basin at bottom sampling station No. 3
 (comp. Fig. 2).

Temperature ($^{\circ}\text{C}$)

	1983								1984							
	7 apr	16 jun	3 jul	29 jul	12 sep	28 nov	12 dec	9 jan	3 feb	11 apr	20 may	8 jun	14 sep	19 okt	6 nov	10 dec
1	2.63	7.32	11.80	8.97	9.07	2.18	2.02	1.24	0.64	2.58	5.12	6.48	8.32	6.30	4.40	2.28
5	2.63	7.20	10.15	8.94	9.03	2.67	3.15	1.27	0.44	2.46	5.09	6.53	8.30	6.32	4.41	2.40
10	2.60	6.59	9.15	8.80	8.92	2.87	3.22	1.34	0.44	2.46	4.85	5.91	8.01	6.33	4.43	2.76
15	2.57	6.13	7.23	8.39	8.67	2.93	2.90	1.43	0.46	2.79	4.71	5.39	7.98	6.34	4.74	2.77
20	2.60	4.66	5.43	6.02	6.16	3.10	2.97	1.44	0.46	2.60	4.22	4.51	6.62	6.33	4.74	2.77
25	2.64	4.50	4.66	4.95	6.09	3.37	2.98	1.40	0.45	2.55	3.90	4.03	6.18	6.61	4.74	2.74
30	2.69	4.36	4.54	4.93	5.93	3.47	3.06	1.40	0.46	2.67	3.84	3.97	5.90	6.64	4.74	2.69
35	2.73	4.35	4.51	4.88	5.86	3.45	3.09	1.30	0.48	2.75	3.83	3.94	5.85	6.71	4.75	2.66
40	2.74	4.34	4.50	4.87	5.83	3.57	3.11	1.32	0.45	2.93	3.83	3.93	5.83	6.72	4.75	2.65
45	2.74	4.34	4.48	-	5.82	3.56	3.12	1.35	0.45	2.95	3.82	3.93	5.82	6.73	4.75	2.65
50	-	4.34	-	-	5.81	3.48	3.13	1.66	0.42	2.96	3.82	3.93	5.81	6.73	4.75	2.63
55	-	-	-	-	-	3.48	-	-	-	2.95	-	3.92	-	-	4.75	-

Salt content (o/oo)

Depth	1983								1984							
	7 apr	16 jun	3 jul	29 jul	12 sep	28 nov	12 dec	9 jan	3 feb	11 apr	20 may	8 jun	14 sep	19 okt	6 nov	10 dec
1	33.40	32.33	29.11	32.70	32.27	32.29	32.38	32.88	33.16	33.39	32.80	31.75	31.91	32.97	33.09	33.13
5	33.40	32.06	30.52	32.69	32.25	32.38	32.57	32.88	33.14	33.46	32.82	32.14	31.93	32.97	32.96	33.12
10	33.42	32.38	31.67	32.72	32.33	32.38	32.61	32.89	33.14	33.49	32.94	32.55	32.35	32.97	32.96	33.22
15	33.45	32.54	32.47	32.77	32.45	32.41	32.58	32.90	33.14	33.57	33.04	32.74	32.57	32.98	33.17	33.28
20	33.47	33.29	33.02	33.01	32.56	32.36	32.61	32.90	33.15	33.54	33.25	33.10	33.02	32.97	33.19	33.30
25	33.48	33.34	33.32	33.26	33.00	32.48	32.62	32.89	33.15	33.56	33.43	33.32	33.08	33.05	33.22	33.30
30	33.50	33.39	33.36	33.27	33.05	32.49	32.65	32.89	33.14	33.57	33.46	33.34	33.13	33.05	33.23	33.30
35	33.51	33.40	33.36	33.28	33.08	32.49	32.66	32.90	33.15	33.60	33.46	33.36	33.14	33.08	33.23	33.31
40	33.51	33.40	33.37	33.28	33.14	32.50	32.66	32.90	33.14	33.63	33.46	33.37	33.15	33.09	33.23	33.31
45	33.51	33.40	33.37	-	33.14	32.50	32.67	32.90	33.15	33.64	33.46	33.37	33.15	33.10	33.24	33.31
50	-	33.40	-	-	33.15	32.50	32.68	32.95	33.14	33.64	33.46	33.38	33.15	33.10	33.24	33.32
55	-	-	-	-	-	32.50	-	-	-	33.64	-	33.38	-	-	33.24	-

Density (σ_t)

	1983								1984							
	7 apr	16 jun	3 jul	29 jul	12 sep	28 nov	12 dec	9 jan	3 feb	11 apr	20 may	8 jun	14 sep	19 okt	6 nov	10 dec
1	26.64	25.04	22.04	25.32	24.97	25.79	25.87	26.33	26.59	26.64	25.92	24.92	24.80	25.91	26.15	26.45
5	26.64	25.08	23.43	25.32	24.96	25.82	25.93	26.33	26.58	26.70	25.93	25.23	24.82	25.91	26.12	26.43
10	26.65	25.41	24.48	25.36	25.04	25.80	25.96	26.33	26.58	26.73	26.06	25.63	25.19	25.91	26.11	26.48
15	26.68	25.60	25.39	25.47	25.17	25.83	25.96	26.33	26.58	26.76	26.15	25.84	25.37	25.91	26.25	26.53
20	26.70	26.36	26.06	25.98	25.34	25.77	25.98	26.32	26.59	26.75	26.37	26.22	25.91	25.91	26.27	26.54
25	26.71	26.42	26.38	26.30	25.96	25.83	25.99	26.33	26.58	26.77	26.55	26.44	26.01	25.93	26.29	26.55
30	26.71	26.47	26.42	26.31	26.03	25.84	26.00	26.33	26.58	26.77	26.55	26.44	26.01	25.93	26.29	26.55
35	26.72	26.47	26.43	26.33	26.05	25.84	26.11	26.33	26.58	26.79	26.58	26.49	26.11	25.95	26.30	26.57
40	26.72	26.48	26.43	26.32	26.10	25.84	26.01	26.33	26.58	26.79	26.58	26.49	26.11	25.95	26.30	26.57
45	26.72	26.48	26.44	-	26.10	25.84	26.01	26.33	26.59	26.80	26.58	26.50	26.11	25.96	26.31	26.57
50	26.72	26.48	-	-	26.11	25.84	26.02	26.35	26.58	26.80	26.58	26.50	26.11	25.96	26.31	26.57
55	-	-	-	-	-	25.84	-	-	-	26.80	-	26.49	-	-	26.31	-

Oxygen (mL/L)

	1983								1984							
	7 apr	16 jun	3 jul	29 jul	12 sep	28 nov	12 dec	9 jan	3 feb	11 apr	20 may	8 jun	14 sep	19 okt	6 nov	10 dec
1	9.63	7.12	7.87	7.90	7.13	7.40	6.05	7.14	7.14	9.21	7.33	7.56	13.22	5.26	5.66	7.43
5	9.77	7.33	8.08	8.17	7.42	7.37	5.80	7.37	6.92	9.11	7.65	7.61	13.59	5.70	5.75	7.39
10	9.70	7.59	8.59	8.06	7.49	7.50	5.74	7.35	7.01	9.20	7.85	8.13	13.47	5.68	5.75	7.31
15	9.58	7.62	8.90	8.01	7.21	7.44	5.79	7.26	6.98	9.25	7.68	8.06	12.66	5.69	5.72	7.29
20	9.34	7.43	9.00	8.31	7.00	7.48	5.79	7.17	6.95	9.21	7.56	7.89	11.96	5.61	5.68	7.25
25	9.13	6.59	7.11	5.38	6.62	7.46	5.74	7.11	6.98	8.76	7.25	7.16	8.24	6.05	5.61	7.27
30	9.00	6.24	6.42	5.62	6.64	7.42	5.70	7.04	6.83	8.34	6.80	6.43	6.41	5.20	5.49	7.30
35	8.85	5.97	6.20	5.61	6.32	7.39	5.67	7.14	6.86	8.17	6.45	6.07	5.54	4.76	5.45	7.28
40	8.77	5.93	6.07	5.36	6.09	7.34	5.67	7.15	6.94	8.06	6.30	5.97	5.20	4.56	5.50	7.24
45	8.88	5.85	5.99	-	3.39	7.20	5.44	7.15	6.96	8.05	6.22	5.82	4.98	4.33	5.49	7.23
50	-	5.81	-	-	3.90	7.20	5.66	7.05	6.85	8.06	6.16	5.78	4.86	4.05	5.47	7.26
55	-	-	-	-	-	7.24	-	-	-	8.06	-	5.78	-	-	5.42	-

Appendix table 2 shows the number of p.e. by consumption of all oxygen (= oxygen quantity in Sept. 1983) and consumption til a residual content of 2 mL/L (= 2.8 mg/L).

Appendix table 2 : Calculated values for water volumes and oxygen quantities at different depths in Nordbotn. Oxygen quantities are converted to p.e. for the whole stagnant period.

A. The entire deep basin

B. Area deeper than 30 m outside Storelva.

A.	Deep area	Volume	Total consumption of oxygen			Residual 2 mL O ₂ /L		
	m	m ³	mg/L	kg O ₂	p.e.	mg/L	kg O ₂	p.e.
	< 20	74 700 000						
	20 - 25	9 600 450	9.5	91 204	6755	6.7	64 323	4764
	25 - 30	5 783 910	7.4	42 800	3170	4.6	26 605	1970
	30 - 35	3 117 960	6.2	19 331	1431	3.4	10 601	785
	35 - 40	1 379 900	5.9	8 141	603	3.1	4 277	316
	40 - 45	473 920	5.6	2 653	196	2.8	1 326	98
	45 - 50	190 530	5.5	1 047	77	2.7	514	38
	50 - 55	55 170	5.4	297	22	2.6	143	10
	> 55	12 500	5.4	67	5	2.6	32	2
Σ		95 314 340		165 540	12 259		107 821	7983
B. Outside Storelva								
	> 30	1 618 540	6.2	10 034	743	3.4	5 503	407

Appendix table 3 : Complete results from hydrographic measurements : Temperature ($^{\circ}\text{C}$), salt content (promille), density ("Sigma" T) and dissolved oxygen (mL/L). The measurements were carried out in the deep area of the Nordbotn Basin at bottom sampling station No. 3 (comp. Fig. 2).

Temperature ($^{\circ}\text{C}$)

	1983										1984									
	7 apr	16 jun	3 jul	29 jul	12 sep	28 nov	12 dec	9 jan	3 feb	11 apr	20 may	8 jun	14 sep	19 okt	8 nov	10 dec				
1	2.63	7.32	11.80	8.97	9.07	2.18	2.02	1.24	0.84	2.58	5.12	6.48	8.32	6.30	4.40	2.28				
5	2.63	7.20	10.15	8.94	9.03	2.07	3.15	1.27	0.44	2.48	5.09	6.53	8.30	6.32	4.41	2.40				
10	2.60	6.59	9.15	8.80	8.92	2.07	3.22	1.34	0.44	2.48	4.85	5.91	8.01	6.33	4.43	2.76				
15	2.57	6.13	7.23	8.39	8.67	2.93	2.90	1.43	0.48	2.79	4.71	5.29	7.98	6.34	4.74	2.77				
20	2.60	4.66	5.43	6.02	6.18	3.10	2.97	1.44	0.46	2.60	4.22	4.51	6.62	6.33	4.74	2.77				
25	2.64	4.50	4.66	4.95	6.09	3.37	2.98	1.40	0.45	2.55	3.90	4.03	6.18	6.61	4.74	2.74				
30	2.69	4.38	4.54	4.93	5.93	3.47	3.06	1.40	0.46	2.67	3.84	3.97	5.90	6.64	4.74	2.69				
35	2.73	4.35	4.51	4.88	5.86	3.45	3.09	1.30	0.48	2.75	3.83	3.94	5.85	6.71	4.75	2.66				
40	2.74	4.34	4.50	4.87	5.83	3.57	3.11	1.32	0.45	2.93	3.83	3.93	5.83	6.72	4.75	2.65				
45	2.74	4.34	4.48	-	5.82	3.58	3.12	1.35	0.45	2.95	3.82	3.93	5.82	6.73	4.75	2.63				
50	-	4.34	-	-	5.81	3.48	3.13	1.66	0.42	2.96	3.82	3.93	5.81	6.73	4.75	-				
55	-	-	-	-	-	3.48	-	-	-	2.95	-	3.92	-	-	4.75	-				

Salt content (o/oo)

Depth	1983										1984									
	7 apr	16 jun	3 jul	29 jul	12 sep	28 nov	12 dec	9 jan	3 feb	11 apr	20 may	8 jun	14 sep	19 okt	8 nov	10 dec				
1	33.40	32.33	29.11	32.70	32.27	32.29	32.38	32.88	33.16	33.39	32.80	31.75	31.91	32.97	33.00	33.13				
5	33.40	32.06	30.52	32.69	32.25	32.30	32.57	32.88	33.14	33.46	32.82	32.14	31.93	32.87	32.98	33.12				
10	33.42	32.38	31.87	32.72	32.33	32.38	32.61	32.89	33.14	33.49	32.94	32.55	32.39	32.87	32.96	33.22				
15	33.45	32.54	32.47	32.77	32.45	32.41	32.58	32.90	33.14	33.57	33.04	32.74	32.57	32.88	33.17	33.28				
20	33.47	33.29	33.02	33.01	32.56	32.36	32.61	32.90	33.15	33.54	33.25	32.74	32.57	32.88	33.17	33.28				
25	33.48	33.34	33.32	33.26	33.00	32.46	32.62	32.89	33.15	33.54	33.43	33.32	33.08	33.05	33.22	33.30				
30	33.50	33.39	33.36	33.27	33.06	32.49	32.65	32.90	33.15	33.60	33.46	33.36	33.14	33.08	33.23	33.31				
35	33.51	33.40	33.36	33.28	33.08	32.49	32.66	32.90	33.14	33.63	33.46	33.37	33.15	33.09	33.23	33.31				
40	33.51	33.40	33.37	33.28	33.14	32.50	32.67	32.90	33.15	33.64	33.46	33.37	33.15	33.10	33.24	33.31				
45	33.51	33.40	33.37	-	33.14	32.50	32.67	32.90	33.15	33.64	33.46	33.37	33.15	33.10	33.24	33.31				
50	-	33.40	-	-	33.15	32.50	32.68	32.95	33.14	33.64	33.46	33.38	33.15	33.10	33.24	33.32				
55	-	-	-	-	-	32.50	-	-	-	33.64	-	33.38	-	-	33.24	-				

Density (σ_t)

	1983										1984									
	7 apr	16 jun	3 jul	29 jul	12 sep	28 nov	12 dec	9 jan	3 feb	11 apr	20 may	8 jun	14 sep	19 okt	8 nov	10 dec				
1	26.64	25.04	22.04	25.32	24.87	25.79	25.87	26.33	26.58	26.64	25.92	24.92	24.80	25.91	26.15	26.45				
5	26.64	25.08	23.43	25.32	24.98	25.82	25.93	26.33	26.58	26.70	25.93	25.23	24.82	25.91	26.12	26.43				
10	26.66	25.41	24.48	25.36	25.04	25.80	25.96	26.33	26.58	26.73	26.08	25.63	25.19	25.91	26.11	26.48				
15	26.68	25.60	25.39	25.47	25.17	25.83	25.98	26.33	26.58	26.78	26.15	25.84	25.37	25.91	26.25	26.53				
20	26.70	26.36	26.06	25.98	25.34	25.77	25.98	26.32	26.59	26.75	26.37	26.22	25.91	25.91	26.27	26.54				
25	26.71	26.42	26.38	26.30	25.96	25.83	25.99	26.33	26.58	26.77	26.55	26.44	26.01	25.93	26.29	26.55				
30	26.71	26.47	26.42	26.31	26.03	26.04	26.00	26.33	26.58	26.77	26.57	26.47	26.09	25.93	26.30	26.57				
35	26.72	26.47	26.43	26.33	26.05	25.84	26.11	26.33	26.59	26.79	26.58	26.49	26.11	25.95	26.30	26.57				
40	26.72	26.48	26.43	26.32	26.10	25.84	26.01	26.33	26.59	26.80	26.58	26.49	26.11	25.96	26.31	26.57				
45	26.72	26.48	26.44	-	26.10	25.84	26.02	26.35	26.58	26.80	26.58	26.50	26.11	25.96	26.31	26.57				
50	26.72	26.48	-	-	26.11	25.84	-	-	-	26.80	-	26.49	-	-	26.31	-				
55	-	-	-	-	-	25.84	-	-	-	-	-	26.49	-	-	-	-				

Oxygen (mL/L)

	1983										1984									
	7 apr	16 jun	3 jul	29 jul	12 sep	28 nov	12 dec	9 jan	3 feb	11 apr	20 may	8 jun	14 sep	19 okt	8 nov	10 dec				
1	9.63	7.12	7.87	7.90	7.13	7.40	6.05	7.14	7.14	9.21	7.33	7.56	13.22	5.25	5.66	7.43				
5	9.77	7.33	8.08	8.17	7.42	7.37	6.80	7.57	6.92	9.11	7.65	7.61	13.59	5.70	5.75	7.39				
10	9.70	7.59	8.59	8.08	7.09	7.50	5.74	7.35	7.01	9.20	7.85	8.13	13.47	5.68	5.75	7.31				
15	9.58	7.82	8.90	8.01	7.21	7.44	5.79	7.26	6.98	9.25	7.68	8.06	12.66	5.69	5.72	7.29				
20	9.34	7.43	8.00	6.21	7.00	7.48	5.79	7.17	6.95	9.21	7.50	7.89	11.96	5.61	5.68	7.25				
25	9.13	6.99	7.11	6.30	6.62	7.46	5.74	7.11	6.98	9.26	7.25	7.16	8.74	5.05	5.01	7.27				
30	9.00	6.76	7.11	6.30	6.62	7.42	5.70	7.04	6.83	9.34	6.80	6.43	6.41	5.20	5.49	7.30				
35	8.85	6.24	6.42	5.82	4.42	7.39	5.67	7.14	6.86	9.17	6.45	6.07	5.54	4.76	5.45	7.28				
40	8.77	5.93	6.07	5.26	4.09	7.34	5.67	7.15	6.94	9.06	6.30	5.97	5.20	4.58	5.50	7.24				
45	8.68	5.85	5.99	-	3.39	7.20	5.44	7.15	6.96	8.85	6.22	5.82	4.98	4.33	5.49	7.23				
50	-	5.81	-	-	3.90	7.20	5.66	7.05	6.85	8.85	6.16	5.78	4.88	4.05	5.47	7.26				
55	-	-	-	-	-	7.24	-	-	-	8.08	-	5.78	-	-	5.42	-				

Appendix table 4 : Complete results from bottom fauna samples (St. N1-N3).
Four parallel samples per station were taken. Each sample represents a bottom area of 0.1 m².

STATION NO. N1				
	No. of Sample 1	No. of Sample 2	No. of Sample 3	No. of Sample 4
NEHERTINI				
Nemertini ind.	12	56	40	33
MOLLUSCA				
<u>Gastropoda</u>				
Margarites helicinus	1	0	0	0
Natica pallida	1	0	0	0
<u>Bivalvia</u>				
Crenella decussata	0	1	0	0
Musculus niger	1	0	0	0
Astarte montagui	9	0	2	0
Parvicardium ovale	5	0	0	0
Macoma calcaria	3	4	4	0
Nys truncata	0	1	0	0
ANNELIDA				
<u>Polychaeta</u>				
Harmeria labricata	8	6	8	14
Pholoe sp.	61	51	31	32
Eteone longa	2	3	0	4
Anatides maculata	3	12	11	12
Typosyllis cornuta	0	1	1	0
Nephtys ciliata	7	0	0	0
Goniada maculata	1	0	0	0
Lumbrineria fragilis	0	0	0	0
Schistomeringos nigridentata	0	0	1	0
Scoloplos armiger	140	12	0	1
Paradoneis lyra	11	13	7	42
Leonice cirrata	0	0	0	1
Spio filicornis	3	25	44	49
Polydora quadrilobata	4	137	76	116
Polydora socialis	430	288	241	154
Polydora caulleryi	0	3	4	0
Cirratulus cirratus	2	0	1	0
Chaetozona setosa	47	204	165	63
Fiabelligera affinis	0	1	0	0
Phoronis plumosa	1	1	0	0
Brada villosa	1	0	0	0
Travisia forbesi	1	0	0	0
Ophelina acuminata	0	8	9	3
Capitella capitata	11	33	14	51
Notomastus sp.	8	0	0	0
Heteromastus filiformis	90	530	500	703
Maldane vari	0	2	0	0
Euclimene spp.	4	2	0	0
Nicomache lumbricalis	2	2	0	0
Owenia fusiformis	8	2	2	3
Pectinaria koreni	1	0	1	0
Sabellides borealis	1	0	0	0
Laphania boeckii	3	0	1	0
Amphitrite cirrata	1	0	0	0
Terebellides stroemi	3	0	0	0
Leonore kroyeri	1	0	0	0
PRIAPULIDA				
Priapulid caudatus	0	1	4	0
CRUSTACEA				
<u>Phyllosaccida</u>				
Nebalia bipes	0	0	0	1
<u>Chaceae</u>				
Diastylis rathkei	1	1	0	0
Amphipoda				
Orchomenella pinguis	1	0	0	0
Menigratopsis svennilssoni	2	0	0	0
Lysianassidae ind.	1	0	0	0
Pontoporeia femorata	0	0	1	0
Paroediceros lynceus	0	0	0	3
Monoculopsis longicornis	0	0	1	0
Monoculodes latimanus	2	0	0	0
Westwoodilla sp.	1	0	0	0
Protomedea fasciata	29	81	103	108
Corophium crassicornis	2	17	22	41
ECHINODERMATA				
<u>Ophiuroidea</u>				
Ophiura robusta	2	0	0	0
<u>Holothuroidea</u>				
Holothuroidea ind.	5	0	0	0
CHORDATA				
<u>Ascidacea</u>				
Ascidia sp.	0	1	0	0

Appendix table 4, cont.

STATION NO. N2

	No. of samples 1	No. of samples 2	No. of samples 3	No. of samples 4
NEMERTINI				
Nemertini ind.	16	9	3	9
MOLLUSCA				
<u>Bivalvia</u>				
Nuculana pernula	2	1	2	4
Musculus discors	0	1	0	0
Musculus niger	0	0	0	1
Astarte crenata	0	0	0	1
Thyasira sarsi	2	3	2	0
Thyasira flexuosa	0	0	0	1
Macoma calcarata	13	14	13	21
Mya truncata	0	0	0	1
Mya arenaria	0	1	0	1
Panopaea norvegica	0	0	1	0
ANNELIDA				
<u>Polychaeta</u>				
Harethos sabricata	2	1	0	1
Pholoe sp.	0	1	0	2
Eteone longa	0	0	0	1
Anatides maculata	1	1	0	0
Syllidae ind.	1	0	0	0
Nephtys ciliata	0	0	0	1
Goniada maculata	0	0	1	1
Schistoserpinus nigridentata	0	0	1	0
Scoloplos armiger	4	9	3	7
Paradoneis lyra	1	0	0	1
Spio filicornis	1	0	0	0
Polydora quadrilobata	0	1	0	0
Chaetozona setosa	3	12	9	15
Cossura longocirrata	30	3	9	0
Capitella capitata	7	1	1	0
Notomastus sp.	0	0	0	2
Heteromastus filiformis	5	26	2	1
Maldane sarsi	5	0	0	5
Euolyene spp.	1	0	0	0
Nicomache lumbricalis	2	0	0	0
Owenia fusiformis	4	1	5	0
Myriochele oculata	0	0	0	1
Pectinaria koreni	3	14	5	1
Sabellides borealis	24	35	34	19
Euophone papillosa	4	9	9	12
<u>Oligochaeta</u>				
Oligochaeta ind.	2	3	0	0
PRIAPULIDA				
Prispulus caudatus	0	0	0	1
CRUSTACEA				
<u>Amphipoda</u>				
Hippomedon propinquus	1	0	0	0
Paroedicerus lynceus	1	0	0	3
Protomeleia fasciata	0	0	0	1
ECHINODERMATA				
<u>Holothuroidea</u>				
Psolus phantapus	0	0	1	0

Appendix Table 4, cont.

STATION NO. N3

	No. of samples 1	No. of samples 2	No. of samples 3	No. of samples 4
CNIDARIA				
<u>Anthozoa</u>				
Tealia felina	1	0	0	0
NEMERTINI				
Nemertini ind.	15	9	9	3
MOLLUSCA				
<u>Gastropoda</u>				
Nudibranchia ind.	0	0	1	0
<u>Caudofoveata</u>				
Caudofoveata ind.	1	1	2	1
<u>Bivalvia</u>				
Ennucula tenuis	0	1	0	3
Nuculana pernula	6	10	5	5
Yoldia hyperborea	0	0	1	0
Musculus discors	0	1	0	0
Musculus niger	3	0	1	0
Astarte montagui	0	1	0	0
Astarte elliptica	3	2	0	0
Thyasira earei	1	2	2	1
Macoma calcarata	62	60	50	57
Mya truncata	2	4	2	4
Mya arenaria	4	2	1	7
Panopea norvegica	5	3	2	0
ANNELIDA				
<u>Polychaeta</u>				
Harmothoe imbricata	1	1	1	0
Pholoe sp.	8	3	3	9
Typosyllis cornuta	0	0	2	0
Nereis pelagica	1	0	0	0
Nephtys ciliata	1	1	0	2
Goniada maculata	0	1	0	2
Scoloplos armiger	6	5	7	11
Paradoneis lyra	0	23	14	20
Spiophanes kroyeri	0	1	0	0
Prionospio cirrifera	0	0	0	1
Chaetozone setosa	1	0	0	2
Cossura longocirrata	3	5	0	0
Pherusa plumosa	1	0	0	0
Heteromastus filiformis	1	0	0	1
Haldane earei	0	3	8	8
Owenia fusiformis	75	211	367	300
Myriochele oculata	234	193	130	170
Pectinaria koreni	0	2	5	4
Sabellides borealis	9	16	3	4
Euchone papillosa	2	7	5	3
<u>Oligochaeta</u>				
Oligochaeta ind.	3	0	2	0
SIPUNCULA				
Golfingia sp.	0	0	0	1
Phascolion strombi	1	2	0	0
PRIAPULIDA				
Priapulus caudatus	0	0	2	0
CRUSTACEA				
<u>Amphipoda</u>				
Paroedicerus lynceus	2	0	0	0
ECHINODERMATA				
<u>Asteroida</u>				
Ctenodiscus crispatus	0	0	2	0
<u>Ophiuroidea</u>				
Ophiura earei	0	0	1	1
Ophiura albida	0	0	5	3
<u>Holothuroidea</u>				
Chiridota leavis	0	0	0	1
Holothuroidea ind.	0	1	0	1
CHORDATA				
<u>Ascidiacea</u>				
Ascidia sp.	1	0	0	0